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Physical Activity and Glycemic control among Adults with Type 2 Diabetes: Evidence from a Cross-Sectional Analytical Study in a Primary Health Centre, Kerala, South India

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Abstract: **Background:** In order to reduce the need for medication in the treatment of Type 2 Diabetes Mellitus (T2DM), physical activity (PA) is essential and has been demonstrated to have established metabolic effects. However, to assess the association between PA intensity and glycemic control in large and heterogeneous groups, thorough research must be conducted. **Methods:** 400 persons with T2DM participated in the cross-sectional study, to assess the association between PA and glycemic levels. Participants were divided into three groups according to their levels of physical activity: low, moderate, and high. Glycated hemoglobin (HbA1c) was used to measure glycemic control; levels of ≤7.0% indicated clinically optimum control. The relationships and prediction power were investigated using a receiver operating characteristic (ROC) curve, one-way ANOVA with Bonferroni corrections, and bivariate correlation analysis. **Results:** The cohort's average age was 57.85 ± 9.27 years, and 55.3% of individuals were females. Of the participants, 39.75% had moderate, 36% higher, and 24.25% lower PA levels. Higher PA was associated with better glycemic management, as seen by a statistically significant negative association with HbA1c ($r = -0.244$, $p<0.01$). The mean HbA1c was 8.77% in the low PA group, 8.03% in the moderate PA group, and 7.67% in the high PA group. These differences were statistically significant ($F(2, 397) = 18.75$, $p<0.001$), with the low PA group having significantly higher HbA1c levels than both the moderate and high PA groups ($p<0.001$). The ROC analysis showed that PA had a fair ability to predict glycemic control, with an AUC of 0.722 (95% CI: 0.673–0.770, $p<0.001$). **Conclusion:** PA was significantly associated with glycemic management in people with T2DM. The results support the inclusion of structured and customized PA plans in routine diabetic care, since this may help lower long-term complications.

Key Words: T2DM, Glycated Hemoglobin, Physical Exercise and Glycemic Control

INTRODUCTION

By 2030, it is expected that 101 million people would have T2DM, which is a serious public health issue, especially in low and middle-income countries like India [1]. Because of its consistently high blood sugar levels, which are brought on by insulin resistance and a relative lack of insulin, this condition can have both microvascular and macrovascular effects if treatment is not received [2]. Type 2 diabetes, which is brought on by dietary changes, sedentary lifestyles, and urbanization, is among the most common in Kerala, India [3].

As a powerful predictor of the health outcomes and death linked to T2DM, glycemic control, often measured by HbA1c levels, essential for efficient disease management [4]. Poor glycemic control has been linked to an increased risk of cardiovascular, nephrotic, and neuropathy problems [5]. The key for its management is altering one's lifestyle, especially through increased physical activity, even while medication is necessary [6]. Figure 2 presents the conceptual framework used in this study, highlighting how physical activity and other factors may influence glycemic control directly and indirectly in individuals with T2DM.

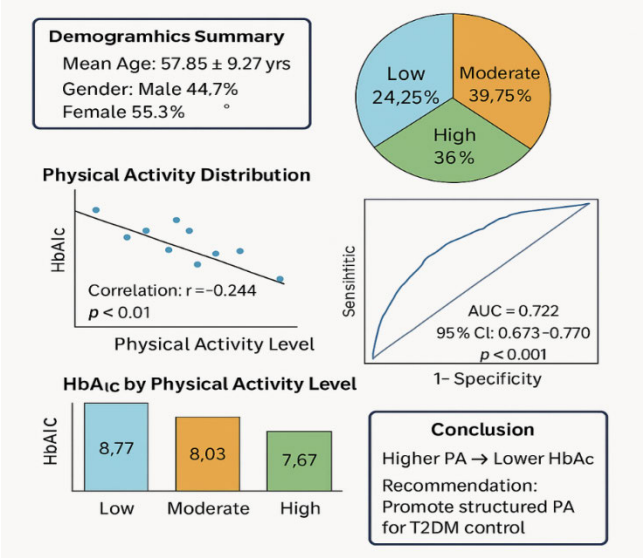

Figure 1: Illustrative Study to Find the Relation Between Glycemic Control and PA

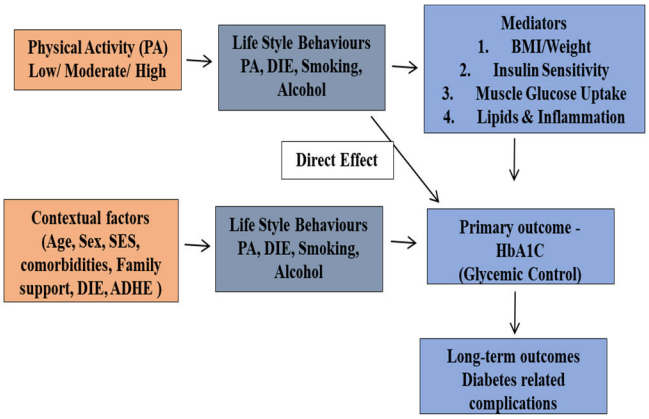

Figure 2: Conceptual Framework Illustrating the Direct and Indirect Components Influencing Glycemic Control in T2DM Patients

Despite growing evidence on physical activity's benefits, Kerala-specific data on inactivity among adults with T2DM remains limited. A 2016 rural Kerala study found that approximately 65.8% of adults aged 15–65 had low levels of physical activity [7]. This gap underscores the relevance of investigating the relationship between PA and glycemic control in T2DM patients in primary care settings.

Physical activity improves insulin sensitivity and glucose utilization, making it an important factor in managing blood sugar levels in people with T2DM [8]. Regular resistance and aerobic exercise can reduce HbA1c levels by 0.5–1% regardless of weight loss [9]. However, a sedentary lifestyle is highly linked to insulin resistance and poor glycemic management, even in people who meet the minimal exercise requirements [10].

Many cross-sectional and longitudinal studies around the world have demonstrated an inverse relationship between physical activity and HbA1c levels [11-12]. However, the intensity of this association differs among populations because of environmental, social, and cultural factors that affect activity behaviors [13]. High BMI, inactivity, and overeating are the main causes of poorer glycemic management in South Asia [14]. Kerala's high life expectancy, growing senior citizen population, and considerable obesity rates make its people particularly noteworthy [15].

Despite growing evidence, primary healthcare data evaluating the relationship between physical activity and glycemic control in rural and semi-urban Kerala are scarce. Although the IPAQ-LF is widely used for assessing physical activity, studies such as [16] have noted potential limitations in accuracy and validity in diabetic populations, suggesting cautious interpretation of self-reported activity data. This information is essential for customizing therapies because of the high rate of overweight and obesity among individuals with T2DM and the low adherence to physical activity guidelines in India [17]. The goal of the current study is to look at how glycemic control and physical activity levels relate to each other in persons with T2DM at a primary health center in Kerala, South India.

Aim and Objectives

In this study, persons with T2DM who are receiving care at a primary health center in Kerala, South India, will have their levels of physical activity and glycemic control examined. MET-minutes per week will be used to measure physical activity patterns, and HbA1c values will be used to assess glycemic management. The study also aims to identify significant clinical (e.g., duration of diabetes, comorbidities], nutritional (e.g., dietary patterns, BMI], and sociodemographic factors (e.g., age, gender, education, income] associated with physical activity and glycemic control. Furthermore, the study will employ multivariable regression analysis to adjust for potential confounders and assess the independent association of physical activity with glycemic control. The predictive ability of physical activity levels for optimal glycemic control will also be evaluated using ROC curve analysis.

METHODS

The Noncommunicable Disease (NCD] Clinic at the Integrated Family Health Centre, Pangappara, which is overseen by the Medical College Health Unit in Thiruvananthapuram, Kerala, India, conducted an analytical cross-sectional study from September 2022 to October 2023. The formula for a single population percentage was used to calculate the sample size, accounting for Kerala's previously reported glycemic control rate of 21.4% [18].

Consecutive sampling techniques were used to enroll 400 participants in total. While consecutive sampling was practical for this study, it may introduce selection bias and limit the representativeness of the sample. The Institutional Ethics Committee granted ethical permission [IEC-NI/19/NOV/71/84], and each subject gave their informed consent. Strengthening the Reporting of Observational

Studies in Epidemiology (STROBE) standards were followed in this study. Adult males and females with T2DM were included; however, subjects with gestational diabetes were not included. Both demographic [age, gender, marital status, family structure, place of residence, educational background, occupation, income, smoking habits, and alcohol consumption] and clinical [duration of diabetes, family medical history, type of treatment, frequency of follow-up, rate of blood glucose testing, participation in diabetes education, comorbid conditions, and complications] data were collected through interviewer-administered questionnaires.

Physical Measurement

Standardized tools were used to record weight and height. Participants wore light clothing and no shoes, and their body weight was measured to the closest 0.1 kg. A stadiometer was used to measure height to the closest 0.1 cm. The BMI could be calculated thanks to these data.

Biochemical Measurement

Each participant had 2.5 cc of whole blood extracted into EDTA tubes in order to assess glycemic control. High-performance liquid chromatography was used in the Medical College Hospital laboratory in Thiruvananthapuram to estimate HbA1c. An HbA1c level of≤7% was deemed to reflect regulated (excellent glycemic control) conditions, whereas values above 7% were categorized as uncontrolled (poor glycemic control), in accordance with the ICMR criteria.

Physical Activity Measurement

Assessment of the Physical activity was performed using the International Physical Activity Questionnaire–Long Form (IPAQ-LF). Work, transportation, housework, and leisure activities are the four categories in which this instrument tracks activities for the past seven days. The activity data was categorized as follows and displayed in MET-minutes per week: Moderate: 600–2999 MET-min/week; High: ≥3000 MET-min/week; Low: <600 MET-min/week. The IPAQ-LF's use in epidemiological research is validated by its internal consistency reliability coefficient of 0.85.

This study follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines to ensure comprehensive and transparent reporting of cross-sectional research [19]. Physical activity was assessed using the International Physical Activity Questionnaire – Long form (IPAQ-LF) a widely used tool whose concurrent validity has been confirmed in recent studies comparing self-reported data with accelerometer measurements [20].

Statistical Analysis

Data were analyzed using SPSS version 28.0. Continuous variables are presented as Mean±SD, and categorical variables as frequencies and percentages. Bivariate analyses, including Pearson correlation and one-way ANOVA with Bonferroni post hoc tests, were used to examine the relationship between physical activity and HbA1c. ROC curve analysis was performed to assess the predictive ability of physical activity for optimal glycemic control (HbA1c ≤7%).

RESULTS

The age distribution of the 400 participants is skewed toward older people, with a mean age of 57.85 ± 9.27 years: 3 (0.8%) were between the ages of 30 and 39, 48 (12.0%) were between the ages of 40 and 49, 132 (33.1%) were between the ages of 50 and 59, and 217 (54.2%) were between the ages of 60 and 69. With 221 out of 400 (55.3%) females and 179 out of 400 (44.7%) males, there was a slight female preponderance. Six (1.5%) reported being separated or divorced, 81 (20.2%) reported being widowed, 57 (14.3%) reported being unmarried, and the majority (256, 64.0%) reported being married. The majority of the households (219, 54.8%) were nuclear, with 21 (5.2%) being joint families and 160 (40.0%) being three-generation households.the participants, 253 (63.3%) said they did not use alcohol or tobacco, whereas 147 (36.7%) said they did. 38 (9.5%) people were in the high strata, 43 (10.7%) were in the lower stratum, and the majority of the population (319, 79.8%) belonged to the medium stratum. In conclusion, this group is primarily composed of older, married, middle-class people living in nuclear families, and about one-third smoke or drink. These are important considerations when interpreting results and when adjusting or stratifying analyses (particularly with regard to age, sex, and SES) because they affect generalizability, as Table 1 illustrates.

Out of the 400 participants, 219 (54.8%) reported having a family history of diabetes, while 181 (45.2%) did not. Of these, 218 (54.5%) had been diagnosed with Type 2 diabetes for 10 years or less, while 182 (45.5%) had the

Table 1: Participant's Sociodemographic Characteristics

Variable	Frequency	Percentage
Mean age	57.85±9.27	-
Age (Years)		
30-39	3	0.8
40-49	48	12
50-59	132	33
60-69	217	54.2
Gender		
Male	179	44.7
Female	221	55.3
Marital status		
Unmarried	57	14.3
Married	256	64
Widow/widower	81	20.2
Separated/Divorced	6	1.5
Type of family		
Nuclear family	219	54.8
Three generation family	160	40.0
Joint family	21	5.2
[Smoking/Alcohol consumption]		
Yes	147	36.7
No	253	63.3
Socio economic status		
Upper	38	9.5
Middle	319	79.8
Lower	43	10.7

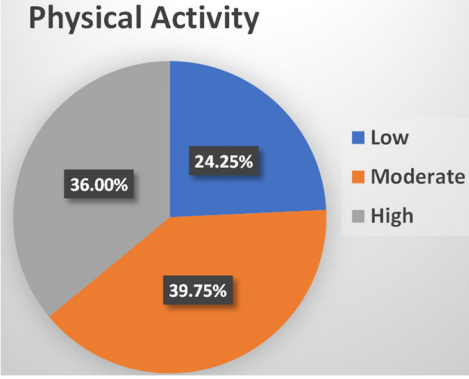

Figure 3: The Percentage of People with Type 2 Diabetes who are Physically Active

Table 2: Clinical characteristics of the Participants

Variable	Frequency	Percentage
Duration of Type 2 DM		
≤10 yrs	218	54.5
>10 yrs	182	45.5
Family history of diabetes mellitus		
Yes	219	54.8
No	181	45.2
Follow up to health care agency		
Regular	194	48.5
Irregular	206	51.5
Regularity of doing blood glucose test		
Regular	171	42.8
Irregular	229	57.2
Family support		
Yes	291	72.8
No	109	27.2
Adhering to diabetic diet		
Regularly	148	37
Occasionally	252	63
Presence of co morbidity		
Yes	304	76
No	96	24
Presence of complication		
Yes	147	36.8
No	253	63.2
Types of medications		
Insulin	17	4.2
Oral hypoglycemic agents	236	59
Both	147	36.8
BMI (Based on South Asian classification)		
Normal	93	23.2
Overweight & obese	307	76.8
Glycemic control		
Good control	165	41.8
Poor control	235	58.2

disease for more than 10 years. Only 171 (42.8%) of the participants routinely performed blood-glucose testing, while 229 (57.2%) did so irregularly. Additionally, 194 (48.5%) of the individuals reported regular visits to a healthcare professional, compared to 206 (51.5%) who had irregular attendance. Family support was substantial, as reported by 291 (72.8%), but diabetes diet adherence was low, with just 148 (37.0%) following the diet consistently and 252 (62.0%) following it occasionally.

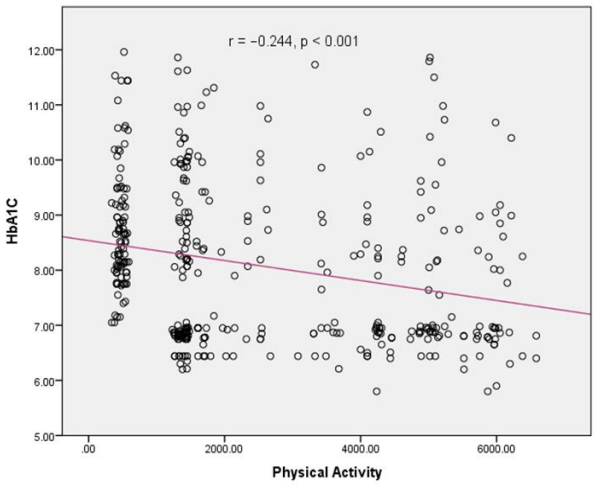

Figure 4: HbA1c and Physical Activity Correlation

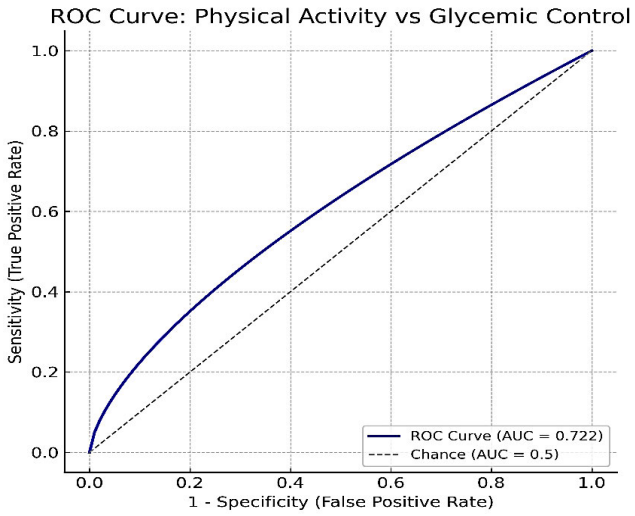

Figure 5: Intensity Threshold Curve between Physical Activity and Glucose Control

A considerable number of patients had comorbid diseases; 304 (76.0%) were impacted, and 147 (30.8%) had at least one diabetes-related consequence. According to treatment patterns, 236 (59.0%) were taking oral hypoglycemic medications only, 147 (36.7%) were taking both insulin and oral medications, and 17 (4.2%) were on insulin only. 307 (76.8%) were categorized as overweight or obese based on South Asian BMI norms, whereas 93 (23.2%) were deemed to be of normal weight. The majority of patients had insufficient glucose control: 165 (41.2%) had good control, while 235 (58.2%) had poor control.

Overall, the findings point to a population with high rates of overweight/obesity and comorbidities, poor self-management (as evidenced by erratic testing, inconsistent follow-ups, and poor dietary compliance), and consequently poor glycemic control. This underscores the need for better lifestyle and weight management interventions, better monitoring and follow-up, and analyses as indicated in Table 2.

Table 3: HbA1c Comparison by Level of Physical Activity

Physical Activity Level	N	Mean HbA1c	Std. Deviation	Mean Difference (vs.)	F (2, 397), p-value	Sig. (Bonferroni)
Low	97	8.77	1.09	Moderate: +0.74 High: +1.10	18.75, p<0.001	0.000 ** 0.000 **
Moderate	159	8.03	1.51	High: +0.36		0.071
High	144	7.67	1.38	-		-
Total	400	8.08	1.43	-		-

Figure 3 Shows how participants' levels of physical activity were distributed, with the biggest percentage, 39.75%, participating in moderate physical activity. The group reporting great physical activity came in second at 36.00%, while the group reporting low physical activity was the smallest at 24.25%. Though almost one-fourth of participants are still classified as low-activity, which may have an impact on their glycemic control and metabolic health, the comparatively higher numbers of those participating in moderate and high activity indicate that the majority of participants engage in some kind of regular physical activity.

Relationship between Physical activity and HbA1c Levels

The descending line [red] indicates a negative correlation (r = -0.244), suggesting that better glycemic management is associated with lower HbA1c readings and higher levels of physical activity, as shown in Figure 4. All HbA1c values in the dataset are positive, consistent with physiological ranges. Even though there is some variation across the data points, the overall pattern supports the beneficial effects of physical activity on blood glucose control. This finding aligns with other studies showing that regular exercise improves insulin sensitivity and supports maintenance of positive glycemic outcomes in individuals with T2DM.

The mean HbA1c levels for the three physical activity groups (Low, Moderate, and High) were assessed using a One-Way ANOVA. The findings showed that the mean HbA1c varied significantly, with F (2, 397) = 18.75 and p<0.001. Post hoc comparisons showed that individuals in the Low physical activity group had significantly higher HbA1c levels than those in the Moderate (p<0.001) and High physical activity groups (p<0.001). However, there was no statistically significant difference in HbA1c levels between the Moderate and High activity groups (p = 0.071), and thus no conclusion can be drawn regarding differences between these two groups. Also, better glycemic management was correlated with higher levels of physical activity, with the high activity group exhibiting the lowest HbA1c levels (Table 3).

Figure 5 illustrates an AUC of 0.722 represents how well physical activity levels distinguish between good and bad glycemic management. Physical exercise provides a moderate ability to differentiate between people with good and bad glycemic control, according to this AUC score. Although not perfect, the ROC curve's position considerably above the diagonal line of chance (AUC = 0.5) suggests that physical activity is a significant predictor of glycemic control. These findings lend credence to the idea that physical activity should be a major behavioral component of diabetes treatment plans.

DISCUSSION

The results of this cross-sectional analytical study indicate a significant correlation between physical activity (PA) and glycemic control in individuals with Type 2 Diabetes Mellitus (T2DM) in Kerala, South India. Participants in the high PA group demonstrated significantly lower average HbA1c levels (M = 7.67 ± 1.38%) compared to those in the moderate PA group (M = 8.03 ± 1.51%) and low PA group (M = 8.77 ± 1.09%). This difference was statistically significant (F (2, 397) = 18.75, p<0.001). High PA was significantly different from low PA (Δ = -1.10%, p<0.001), while the difference between moderate and high PA groups (Δ = -0.36%) did not reach statistical significance (p = 0.071), indicating a trend rather than a definitive effect. The ROC AUC of 0.722 suggests that PA has a reasonable ability to predict glycemic control status, with a negative correlation (r = -0.244).

These findings align with previous meta-analyses indicating that moderate to high levels of aerobic and resistance exercise can reduce HbA1c by 0.5%–0.7% [20]. The observed dose-response relationship in this study, where HbA1c decreased with increased intensity and regularity of PA, is consistent with global guidelines, including those from the ADA [2], WHO [21], and ICMR [22]. For instance, structured aerobic exercises, such as walking, yoga, or weight training, have been shown to improve glycemic control in randomized controlled trials (RCTs) in Indian populations [23-24].

The current study also supports findings from wearable and behavioral models, which similarly report moderate to high accuracy in predicting glycemic trends. For example, studies using accelerometers in Western populations have demonstrated AUCs of 0.70–0.80 [25-26], reinforcing the potential for integrating wearable PA monitoring into diabetes management in primary care settings in India.

Additionally, mobile health [mHealth] interventions have been effective in improving PA adherence, with several studies showing reductions in HbA1c of 0.4% to 0.9% [27-28]. Community-based fitness initiatives like yoga and walking groups in Kerala also support sustained PA and better glycemic control [29-30].

After adjusting for confounding factors such as age, gender, BMI, and duration of diabetes using multivariable regression analysis, the significant association between physical activity and glycemic control remained robust. This adjustment provided a clearer understanding of the independent role of physical activity in improving glycemic control in people with T2DM. The analysis showed that even after controlling for these factors, higher physical activity levels were consistently associated with lower HbA1c levels.

This adds strength to the claim that physical activity has a direct impact on managing glycemic control, independent of other known risk factors. However, as the cross-sectional design limits causal inference, further longitudinal studies are necessary to confirm the observed relationship between PA and glycemic control.

Implications for Practice

This study underscores the importance of integrating physical activity promotion into the routine management of Type 2 Diabetes Mellitus (T2DM) in primary care settings. The results suggest that moderate levels of PA are significantly associated with improved glycemic control. Clinicians can confidently recommend moderate PA as part of diabetes care to help manage HbA1c levels. The ROC analysis also highlights the potential utility of self-reported tools like the IPAQ-LF for initial screening of PA levels in clinical settings.

The high prevalence of poor glycemic control observed in the study emphasizes the need for timely interventions. Furthermore, promoting culturally appropriate, community-level physical activity initiatives may enhance engagement and adherence, particularly in regions with limited access to structured exercise programs.

CONCLUSIONS

This observational study conducted at a primary health center in Kerala, India, among 400 individuals with T2DM, demonstrates a significant association between physical activity (PA) and glycemic control. Participants in the high PA group showed better glycemic control; with significantly lower mean HbA1c levels compared to those in the moderate and low PA groups. Statistical analysis revealed significant differences between the groups ($F(2, 397) = 18.75$, $p<0.001$), supported by post-hoc comparisons and a ROC curve AUC of 0.722, indicating a moderate predictive ability of PA for glycemic control.

The results highlight a clear dose-response relationship, suggesting that even modest increases in physical activity may yield clinically meaningful improvements in glycemic control. Integrating routine PA assessments into diabetes management protocols in primary care settings can help identify individuals at risk of poor glycemic control. Culturally tailored interventions that promote sustained physical activity should be prioritized within primary health programs to improve metabolic outcomes.

However, the cross-sectional nature of the study and reliance on self-reported physical activity limit the ability to infer causality, and may introduce reporting biases. Future research using longitudinal designs and objective PA measurements is warranted to further validate these findings.

Limitations of the Study

While this study provides valuable insights into the relationship between physical activity and glycemic control, several limitations must be acknowledged. First, the cross-sectional design of the study restricts the ability to establish a causal relationship between physical activity and HbA1c levels. Since data were collected at a single point in time, this design only allows for associations to be drawn rather than causality. Furthermore, the reliance on self-reported physical activity, measured using the IPAQ-LF questionnaire, introduces the potential for recall bias and social desirability bias, which may lead to overestimation or underestimation of actual physical activity levels. Although interviewer-administered questionnaires were used, the formal training of interviewers was not documented, potentially introducing interviewer bias that could affect the consistency and accuracy of responses. Additionally, since physical activity levels may vary with seasons, and the data were collected year-round, the lack of consideration for seasonal variation may have influenced the accuracy of the reported activity levels and their association with glycemic control.

The study sample was drawn from a single primary health center, which limits the generalizability of the findings to other regions or healthcare settings. The use of consecutive sampling may not fully represent the entire clinic population, introducing a potential selection bias and limiting the diversity of participants. Furthermore, the non-response rate was not documented, which could introduce participation bias, as individuals who declined to participate may differ systematically from those who participated. Moreover, several potential confounding variables such as dietary habits, medication adherence, psychological stress, and co-existing medical conditions were not accounted for in the analysis. This means that physical activity alone may not fully explain the changes observed in HbA1c levels. Lastly, the study did not assess quality of life, which could be an important factor in understanding the broader effects of physical activity on individuals with T2DM. Future research should address these limitations by considering long-term changes in physical activity and HbA1c, as well as using objective measures of physical activity, such as accelerometers, to strengthen the evidence base.

Future Recommendations

Given the cross-sectional nature of this study, longitudinal studies are needed to establish a causal relationship between physical activity and glycemic control. Future research should explore the effectiveness of mHealth interventions to enhance physical activity adherence and provide real-time feedback to improve long-term outcomes for individuals with Type 2 Diabetes. Furthermore, community-based physical activity programs, such as walking clubs, yoga sessions, and group exercise programs, should be investigated for their potential to increase engagement and provide sustained motivation for physical activity, particularly in resource-limited settings. These community-based initiatives could be particularly beneficial when tailored to the cultural context, and their impact on both short-term and long-term outcomes should be measured.

Future research should prioritize qualitative studies to gain in-depth insights into the personal, social, and environmental barriers that individuals with Type 2 Diabetes face in engaging with physical activity. Understanding these barriers through qualitative methods can inform the

development of tailored interventions that address the unique challenges of this population, thereby enhancing adherence and improving glycemic control.

Additionally, structured PA should be incorporated as a key component of diabetes management. Structured PA programs, including both aerobic exercises [e.g., walking, cycling] and resistance training [e.g., weight training], should be systematically integrated into diabetes care protocols. These programs should be supervised by healthcare professionals to ensure the proper intensity and adherence to activity guidelines. Personalization of PA programs is essential to cater to the individual's health condition, capabilities, and preferences, which may improve engagement and outcomes. Finally, future studies should incorporate objective physical activity measurements, such as accelerometers, to provide more accurate data on the relationship between physical activity and glycemic control.

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